

IMPROVING THE RELIABILITY OF TECHNOLOGICAL SUBSYSTEMS EQUIPMENT FOR STEAM TURBINE UNIT IN OPERATION

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Abstract. The authors' conception is presented of an integrated approach to reliability improving of the steam turbine unit (STU) state along with its implementation examples for the various STU technological subsystems. Basing on the statistical analysis of damage to turbine individual parts and components, on the development and application of modern methods and technologies of repair and on operational monitoring techniques, the critical components and elements of equipment are identified and priorities are proposed for improving the reliability of STU equipment in operation. The research results are presented of the analysis of malfunctions for various STU technological subsystems equipment operating as part of power units and at cross-linked thermal power plants and resulting in turbine unit shutdown (failure). Proposals are formulated and justified for adjustment of maintenance and repair for turbine components and parts, for condenser unit equipment, for regeneration subsystem and oil supply system that permit to increase the operational reliability, to reduce the cost of STU maintenance and repair and to optimize the timing and amount of repairs.

According to [1], one of the main problems of modern and forthcoming activity of the electric power industry is a rapid increase of the equipment wearing out, which has already reached 60%.

The aging of equipment is accompanied by a decrease in its reliability and by an increase in the amount of damages. So it is necessary to ensure the operation reliability of the above-mentioned fleet of equipment, regardless of its operating time.

It is known that in order to improve the reliability of steam turbine units (STU) equipment under operating conditions a complex of works on repair and maintenance of equipment is accomplished, according to [2,3], and only in some particular cases the works are carried out for unreliable units modernization. This approach is aimed mainly at maintaining the equipment in serviceable condition and does not provide the necessary increase in reliability. At the same time, this approach is applied to all types of equipment and it does not take into account the specific design and operating conditions of specific equipment.

This paper presents the results of the authors' research into the development and implementation of an integrated approach concept to improving the reliability of steam turbine plant state under operating conditions.



The main works performed for the implementation of the integrated approach are presented in the diagram (Figure 1). The proposed integrated approach includes:

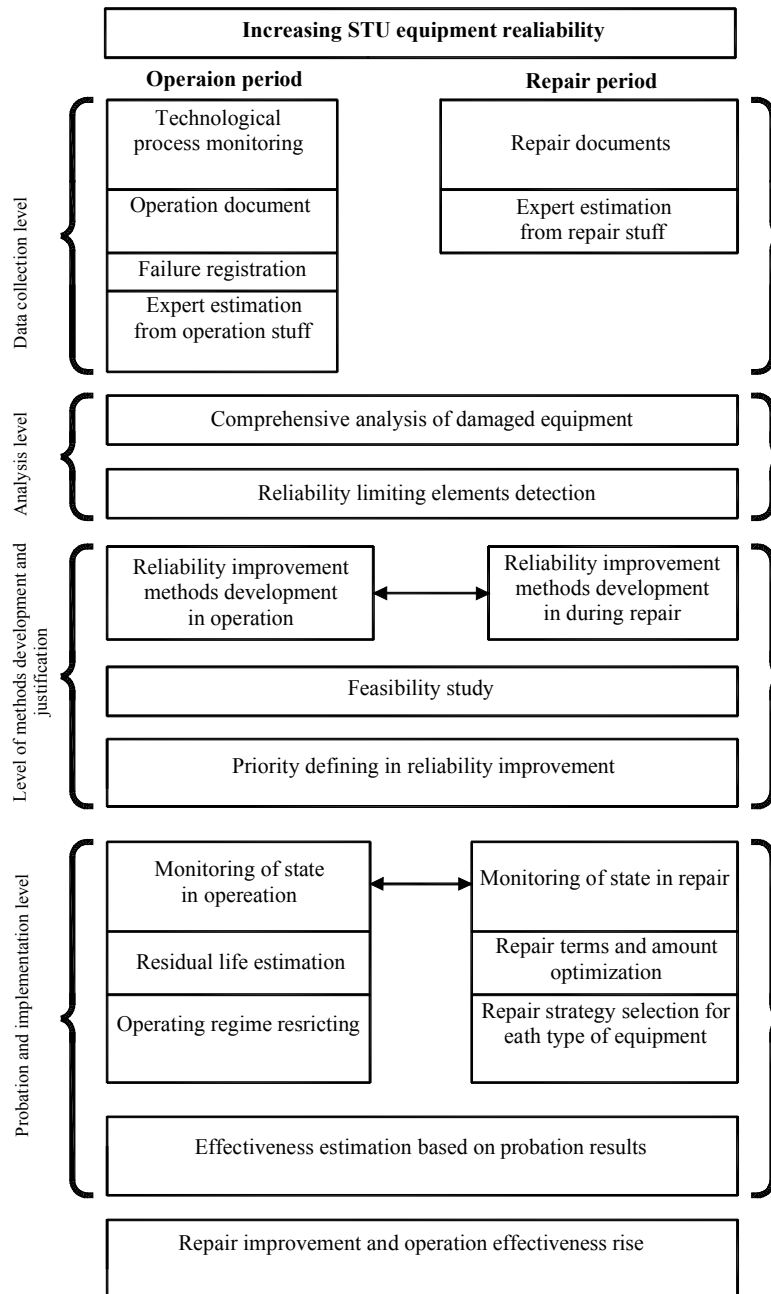


Figure 1. Implementation procedure for an integrated approach to equipment reliability improving

- collection of data on the equipment damageability on the basis of information obtained during the operation and during the repair period;
- equipment damage analysis:
 - identification of equipment parts and components limiting the reliability;
 - analysis of the main factors that lead to the damageability of these parts and equipment components;

- analysis of design features of these parts and components in comparison with the design of similar equipment units of other standard sizes in operation;
 - analysis of design features of these parts and components in comparison with the up-to-date design of similar equipment units;
- the development of methods for improving the units of limited reliability:
 - analysis of the possibility of using known (employed on equipment of other standard sizes) design and technological solutions to improve the reliability of these units;
 - analysis of the possibility of applying of methods and technologies that are used in other branches of science and technology to eliminate similar problems;
 - new technical solutions, methods and technologies development;
- carrying out feasibility studies of planned activities;
- determination of priority directions for increasing the reliability of a particular steam-turbine plant in relation to its operating and repair conditions;
- for STU parts with structural defects:
 - experimental and industrial implementation of measures to eliminate the defect and the causes of its occurrence;
 - analysis of the effectiveness of above mentioned measures for equipment of a specific size and recommendations development for the implementation of this measures on similar equipment;
- for STU equipment parts with defects caused by physical deterioration or operating conditions:
 - implementation of monitoring of state for equipment parts and components that limit its reliability;
 - evaluation of residual life for equipment parts and components that limit its reliability;
- adjustment of maintenance and repair system for STU equipment with reference to measure to improve the reliability of parts, limiting its reliability, to monitoring systems data and specific operating conditions:
 - repair strategies selection that meets the operating requirements of the particular type of equipment;
 - repair timing and volumes optimization for particular type of STU equipment.

The implementation of this approach permits to increase reliability of operation, to cut maintenance and repair costs and to reduce losses of power plants from underproduction of electricity and heat as well as penalties due to unplanned shutdowns. Within the framework of the study, in accordance with the concept, a statistical analysis was performed of the damageability under the operation conditions for turbine parts and equipment of the following STU technological subsystems:

- oil supply subsystem (oil pumps, oil coolers, oil lines),
- condenser unit — condenser itself, ejectors, condensate pumps,
- low-pressure regeneration subsystem (low-pressure heaters (LPH), gland heaters),
- high pressure regeneration subsystem (high pressure heaters (HPH)),
- network water heating subsystem (hot water heaters),
- feedwater subsystem (feeding motor pumps (FMP), feeding turbine-driven pumps (FTP), booster pumps, deaerators),
- circulation water supply subsystem (circulation pumps).

In addition, in accordance with the concept for the same equipment, an analysis was performed of the defects detected during the repair. Based on the reliability analysis of power units, it was determined that malfunctions of the equipment of steam turbine units (turbines and auxiliary equipment of the STU) account for 25—30% of the total number of unit failures.

An analysis of the causes leading to turbine failures has shown that the greatest number of failures is caused by the control system damages (up to 28%) and by the supporting bearing damages (up to

25%). For a number of turbine sizes, a large number of damages occur in the steam distribution system (up to 20.6%). Figure 2 presents the authors' generalized data on damages of turbine assemblies for various type turbines with the capacity of 100—800 MW and of different manufacturing plants.

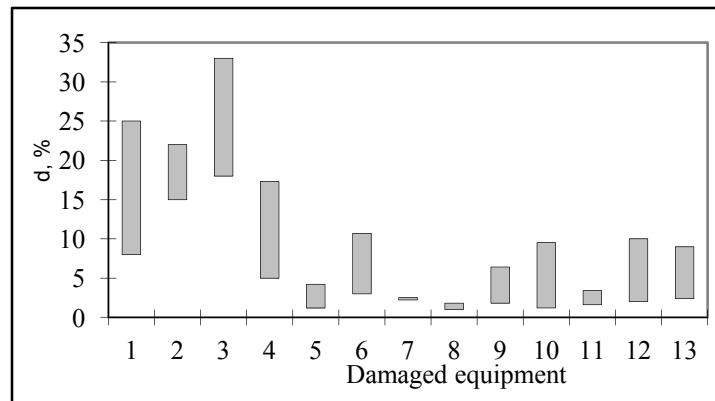


Figure 2. Turbine failure distribution due to:

1 - flowing part damage; 2 - steam distribution systems damage; 3 - control systems damage; 4 - damage of bearings; 5 - oil systems damage; 6 - damage of pipelines and valves; 7 – other

Based on the analysis of the damageability of technological subsystems equipment, it was revealed that the most damageable equipment is the condenser along with feedwater turbine-driven pumps (Figure 3). Table 1 presents the results of the analysis of malfunctions leading to a turbine shutdown (failure) for STU various technological subsystems equipment operating in unit plants and steam power plants with transverse connections.

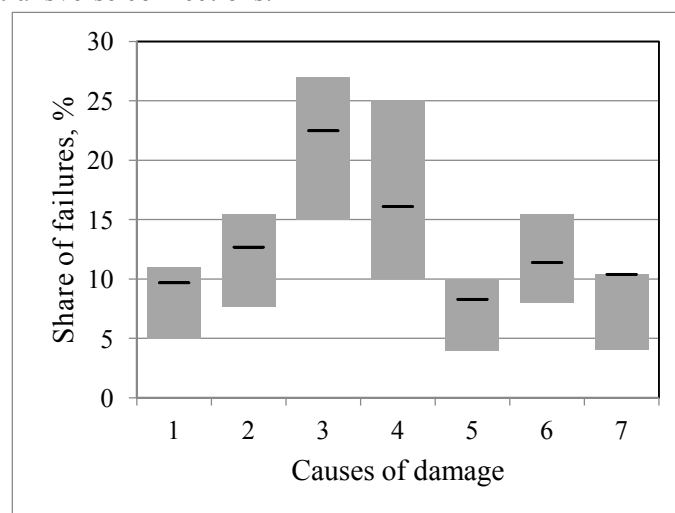


Figure 3. Failure distribution for auxiliary equipment of turbine units:

1 - condensers; 2 - feeding motorpumps; 3 - feeding turbine-driven pumps; 4 - high pressure heaters; 5 - low pressure heaters; 6 - gland seal heaters; 7 - ejectors; 8 - deaerators; 9 - circulating pumps; 10 - condensate pumps; 11 - booster pumps; 12 - valves; 13 – piping

When examining the defects revealed during the repair, it is established that a significant number of defects in the bearings and in the flowing part of the turbines are caused by disturbances in the state and by defects in the thermal expansion system.

On the basis of the analysis, the critical (most damageable) turbine assemblies (parts) and auxiliary turbine equipment that limit the reliability of the turbine unit are determined, for which it is necessary to develop the methods of their reliability increase. These components include: a regulation and steam distribution system, bearings, a system of thermal expansion of turbines and tube bundles of heat exchangers.

Table 1. Effect of technological subsystems equipment failures on STU off-scheduled shutdowns

Technological subsystem	Technological subsystem equipment	Share of equipment failures that led to STU shutdown, %	
		Turbines of power plants	Turbines of power stations with transverse connections
Condenser unit	Condenser	100	89
	Ejectors	93	97
	Condensate pumps	71	42
	Circulation pumps	37	34
Low pressure feedwater regenerative heating system	LPH ¹	90	52
	Gland seal heaters (for turbine plants with only one gland seal heater)	95	90
High pressure feedwater regenerative heating system	HPH	34	11
Hot water heating system	Hot water heaters	0	0
Feed water system	FTP	34	26
	FMP	75	34
	Booster pumps	53	0
	Deaerators	100	47
Oil supply system	Oil coolers		12
	Oil tank		90
	Oil lines		65
	Valves		
	Main oil-dispensing pump		100
	Oil-lubricating injector		100

To increase the reliability of the turbine units, first of all, it is necessary to eliminate the causes that lead to assemblies (parts) failures and, as a consequence, to equipment unplanned shutdowns.

Most of the control system failures are caused by the mechanical wear of the parts, by low oil quality and by poor quality of manufacturing. This is due to the use of traditional hydro mechanical control systems. The transition to electro-hydraulic automatic control systems on microprocessor technology, in which there is no parts usually damaged in traditional systems, will reduce the total number of turbine failures by 15—20%.

The most common defects of turbine bearings are those of babbitt filling, which are manifested in changes of the turbine vibration state and in oil leaks from the bearing along the turbine shaft. The

¹ According to the authors, the failure of the LPH in most cases does not lead to a turbine shutdown. This may mean that a significant number of incidents related to the LPH are not registered in official failure documents.

implementation of vibration monitoring systems that continuously monitor the condition of bearings will help to prevent unplanned shutdowns caused by defects in babbitt filling and, thereby, to reduce the total number of turbine failures by 2.0—5.0% and, accordingly, to reduce the unplanned downtime of turbines by 4.0—6.0%. The development of measures for oil leakages prevention from bearings will reduce the total number of turbine failures by 0.5—1.0% and unplanned downtime by 1.0 — 1.5%. Another 0.5% of the total number of turbine failures can be prevented by improving the oil quality.

As to the steam distribution system of turbines a significant number of damages occur in the steam distribution mechanism due to the jamming of the tappet shaft supporting bearings and, as a consequence, to the destruction of the bearing separator. Elimination the causes of bearings jamming will reduce the total number of turbine failures by 1.8—4.2% and reduce the unplanned downtime by 0.8—2.9%. Also a significant number of unplanned turbine shutdowns are caused by damages of the control valves, due to mechanical wear of the rods, boxes and threaded joints of the rod with other elements because of prolonged operation. Repair timing optimization for steam distribution systems will reduce the total number of turbine failures by 1.1—2.5% and accordingly reduce the unplanned downtime by 0.5—1.7%.

To increase the reliability of heat exchangers operation, the priority is to optimize the replacement period for tube bundles, as well as to improve the reliability of the valves.

Below, as an example of the implementation of the concept, solutions developed by the authors for some critical elements are presented.

Based on the analysis of damageability, it was revealed that the majority of failures of T-100-130 turbine of UTZ manufacturing and its modifications are caused by damages of steam distribution cam mechanism (supporting bearings jamming and consequent destruction of their separators).

Analysis of operating conditions, repair documentation and manufacturer solutions showed that the damage occurs according to the following mechanism: when the turbine is operated with a constant capacity the grease is sintered (stuck) between the separator and the bearing rollers and the seizure of the bearing due to the increased air temperatures in the area of the cam mechanism; if it is necessary to change the capacity of the turbine, the servomotor tries to turn the gear, the residue formed in the bearing prevents the separator moving and an effort arises in the bearing, which leads to separator damage.

To eliminate supporting bearings jamming it was proposed to exclude the use of greases in this unit and to treat the bearings with fluorine-containing surfactants, based on epilam. A special technology was developed and protected by the author's certificate [4] for applying epilam solution to the friction surface in the roll bearing, which provides full treatment of the separator and the bearing rollers thus ensuring their surface hardening and giving it anti-corrosion and antifriction properties.

Experimental and industrial probation of this technology showed that the treated bearing sets worked without damage through the planned overhaul period, which amounted to 5—7 years for different turbines (similar bearings without treatment worked for 6—8 months).

The distinction of heat exchangers is that they contain a large number of similar elements — heat exchange tubes. This allows us to use statistical methods for analyzing the damageability of heating surfaces, justifying the term of repairs and replacement of equipment.

For turbine condensers a technique has been developed that makes it possible to estimate the beginning of the period of tube systems service life exhaustion [5]. Condenser operation during this period is extremely undesirable, since there is a danger of sudden massive tube damage, of water-chemical regime disturbances in the power unit and its shutdown. The technique is based on the analysis of censored samples of condenser tubes operating age. The operating age of the tubes that are plugged during the operation of the power unit are included in the full sample, and the tubes that are plugged during the repair process are censored sampling. The time when distribution function for the full sample exceeds the confidence interval calculated with the use of the censored sample points the time for replacing the condenser tube system. The results of this technique approbation at 11 power

units showed that the mass tube failure starts in 1.2—2 years after the calculated time, which allows the personnel of power plants to get ready for condenser repair (for tube system replacement).

When analyzing the damageability of high-pressure turbine heaters, it was taken into account that as a result of HPH repairing and replacement of defective spirals, the HPH service life is recovered almost completely. For the analysis of HPH damage the information was collected on emergency and scheduled repairs of heaters, on the timing between repairs and their duration [6]. Dependences have been obtained for HPH failure and recovery rates. Employing Markov processes, a system of equations is formulated that determines the probability of equipment transition from serviceable state to repair state. As a result of the system of equations solving it is established that the maximum probability of HPH failure after repair is 0.045 and manifests itself in 2—2.5 months. After this period, the probability of HPH failure decreases. The revealed features of HPH failures characterize the quality of its repair and the increased probability of the heater failure during seating-in period after the next repair.

According to the analysis of the features of STU equipment operation and repair, it is advisable to apply individual repair strategies for various types of equipment and to establish the periodicity of repair for each part of the turbine unit. For steam turbine assemblies a number of recommendations for repair optimization are formulated on the basis of the damageability analysis and of the dependence of damage against time after the repair, such as:

- - reduce the repair period to 30 thousand hours for the regulation and the steam distribution systems;
- - when a turbine operating age is about 30 thousand hours, it is advisable to carry out a set of examination measures, and according to the examination results to perform measures to normalize the operation of the thermal expansion system.

The proposed concept allows us to formulate and justify recommendations for choosing a repair strategy for STU heat exchangers:

- - for oil coolers a scheduled preventive repair is the most appropriate;
- - for heaters of the feedwater regenerative heating system it is advisable to carry out repairs according to the equipment actual state on the basis of a feasibility study;
- - for steam turbine condenser it is advisable to carry out repairs according to its actual state, while the governing factor is the residual life of the condenser tubes.

The concept of a comprehensive increase in steam-turbine units reliability, proposed in this paper, was tested on the equipment of STU technological sub-systems under operational conditions and made it possible to identify and eliminate the causes leading to the reliability decrease both of STU equipment and of STU in general.

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